Forces and Motion
PS-5 The student will demonstrate an understanding of the nature of forces and motion.

PS-5.1 Explain the relationship among distance, time, direction, and the velocity of an object.
Taxonomy Level: 2.7-B Understand Conceptual Knowledge

Key Concepts:
Distance, Direction, Displacement
Speed: Average speed, Instantaneous speed, Initial speed, Final speed
Velocity: Average velocity, Instantaneous velocity, Initial velocity, Final velocity
Rate

Previous/Future knowledge: In 5th grade, students summarized the motion of an object in terms of position, direction, and speed (5-5.2). In 8th grade, students used measurement and time-distance graphs to represent the motion of an object in terms of its position, direction, or speed (8-5.1) and also used the formula for average speed, v = d/t to solve real-world problems (8-5.2).
Physical Science requires that students expand on the idea that direction is an important aspect of the motion of an object. Students will compare the concepts of distance and displacement. The term "velocity" is used for the first time, and students will differentiate speed and velocity. The concept of how direction is an important aspect of motion is the basis for the study of vector motion in subsequent physics classes. Also, an understanding of the duel nature of velocity (speed and direction) is essential before students can understand how forces affect the motion of objects (Newton's laws of motion).

It is essential for students to

- Understand ***Distance and Displacement***:
  - *Distance* is a measure of how far an object has moved and is independent of direction.
    - If a person travels 40m due east, turns and travels 30m due west, the *distance* traveled is 70m.
  - *Displacement* has both magnitude (measure of the distance) and direction. It is a change of position in a particular direction. For example: 40m east is a displacement.
  - *Total* or *final displacement* refers to both the distance and direction of an object's change in position from the starting point or origin. Displacement only depends on the starting and stopping point. Displacement does not depend on the path taken.
    - If a person travels 40m due east, turns and travels 30m due west, the *total displacement* of the person is 10m east.
    - If a person travels 40m east and then travels another 50m east the *total displacement* is 90m east.
- Understand ***Speed***:
  - *Speed* is how fast something is going. It is a measure of the distance covered per unit of time and is always measured in units of distance divided by units of time. (The term "per" means "divided by")
  - Speed is a *rate* as it is a change (change in distance) over a certain period of time
  - Speed is independent of direction.
  - The speed of an object can be described two ways
  - *Instantaneous speed* is "the speed at a specific instant". *Initial speed* and *final speed* are examples of instantaneous speed. A speedometer measures instantaneous speed.

- *Average speed* is "the total distance covered in a particular time period"
  - If an object is traveling at a constant speed, the instantaneous speed at each point will be equal to the average speed.
  - If an object is traveling with varying speeds, the average speed is the total distance covered divided by the total time.
- Understand ***Velocity****:*
  - *Velocity* refers to both the speed of an object <u>and</u> the direction of its motion.
  - A velocity value should have both speed units and direction units, such as: m/sec north, km/h south, cm/s left, or km/min down.
  - Velocity is a rate because it is a change in displacement over a certain period of time.
  - The velocity of an object can be changed in two ways:
    - The speed of the object can change (it can slow down or speed up).
    - The direction of an object can change. (A racecar on a circular track moving at a constant speed of 100 km/h has a constantly changing velocity because of a changing direction of travel.)
  - The velocity of an object can be described two ways:
    - *Instantaneous velocity* is the velocity at a specific instant. *Initial velocity* and *final velocity* are examples of instantaneous velocity.
    - *Average velocity* is the total (final) displacement in a particular time.

Assessment Guidelines:
The objective of this indicator is to *<u>explain</u>* the relationship among distance, time, direction, and the velocity of an object, therefore, the major primary focus of assessment should be to construct ~~a~~ cause and effect models relating how each variable affects the motion of the object, as well as the effect of combinations of variables on motion.

In addition to *explain*, assessments may require that students:
- *<u>Exemplify</u>* how each variable influences the motion of an object;
- *<u>Compare</u>* distance to displacement and velocity to speed;
- *<u>Summarize</u>* the effect of each variable separately or in combination on the motion of an object; (speed, velocity, time, distance, or displacement)
- *<u>Infer</u>* from experimental data the relative speed or velocity of an object (faster vs. slower);
- *<u>Illustrate</u>* in words pictures or diagrams the effect of these variables on the motion of an object.

PS-5.2 Use the formula v = d/t to solve problems related to average speed or velocity.
Taxonomy Level: 3.2-C Apply Procedural Knowledge

Key Concepts:
Average speed (v)
Distance (d)
Elapsed time (t)
Average velocity (v)
Displacement (d)

Previous/Future knowledge: 8th grade students used the formula for average speed, v = d/t to solve real-world problems (8-5.2). In 8th grade the concept is "speed" even though the variable is represented by a "v". In PS-5.1 students develop a conceptual understanding of the idea that direction is an important aspect of the motion of an object and compare the concepts of distance and displacement. The term "velocity" is used for the first time, and students differentiate speed and velocity (PS-5.1). This indicator addresses the mathematical dimension of motion solving for average speed or velocity. Physical Science students will need to rearrange the equation v = d/t to solve for any of the variables.

It is essential for students to
- Understand the correct context for the variables in the word problem when using the equation v = d/t.
  - In the equation, "v" can represent either velocity or speed and "d" can represent either displacement or distance, depending on the context of the problem. The differences are addressed in PS-5.1
  - The term "speed" or "velocity" refers to average speed or velocity.
  - Students must determine the "given" information in a problem using the correct units. See sample table:

Variable	Abbre-viation	Units	Direction required?	Examples	
Speed	v	distance/time	No direction	m/s	22 cm/yr
Velocity	v	distance/time	With direction	m/s north,	36 km/h west
Distance	d	distance	No direction	15m	30.0 km
Displacement	d	distance	With direction	546 km down	24.9 m west
Time	t	time	NA	15 s	32 days

- Use the formula, v = d/t.
  - Students must be able to calculate average speed.
    - When calculating *average speed* using v = d/t: the average speed for the trip equals the total distance divided by the total time. Ignore the direction of the motion.
  - Students must be able to calculate average velocity.
    - When calculating *average velocity* using v = d/t: the average velocity equals the total displacement divided by the total time.
      - The total displacement may be different from the total distance.
      - When indicating the average velocity, direction must be given and the average velocity will have the same direction as the total displacement.

- * The total displacement is the (straight line or shortest) distance and direction from the starting point.
- * If the direction of the motion is changing, the velocity will not be constant even if the speed is constant.

- o Students must be able to rearrange the equation to solve for any of the variables. Example: d = vt, or t = d/v
- o The instantaneous velocity at any point will not necessarily be the same as the average velocity.

Teacher note: The students are only responsible for velocity problems in which the total or final displacement is given.

It is not essential for students to
- Convert Standard English units to metric units;
- Solve problems involving scientific notation;
- Calculate average velocity using displacement when total displacement is not given; (They do not need to solve for total displacement first.)
- Solve velocity problems involving vector addition.

Assessment Guidelines:
The objective of this indicator is to *use* the formula v=d/t to solve problems, therefore the primary focus of assessment should be to apply the velocity equation to a novel word problem or set of laboratory data, not just repeat problems that are familiar. -

In addition to *use*, assessments may require that students:
- *Apply* procedures for manipulating the velocity equation;
- *Recall* the differences between speed and velocity as to whether a direction is needed;
- *Identify* the units needed in the solution to a problem.

Forces and Motion
PS-5 The student will demonstrate an understanding of the nature of forces and motion.

PS-5.3 Explain how changes in velocity and time affect the acceleration of an object.
Taxonomy Level: 2.7-B Understand Conceptual Knowledge

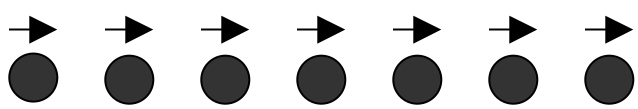
Key Concepts:
Acceleration

Previous/Future knowledge: In 8^{th} grade, students used measurement and time-distance graphs to represent motion of an object in terms of its position, direction, or speed (8-5.1); analyzed the effects of forces (including gravity and friction) on the speed and direction of an object (8-5.3); and analyzed the effect of balanced and unbalanced forces on an object's motion in terms of magnitude and direction (8-5.5). These indicators address how forces influence the motion of an object, and in each case the answer is that a force can cause the speed of an object to increase or decrease or the direction of the object's motion to change. However, 8^{th} grade students do not consider the concept of acceleration. With an understanding of velocity in terms of speed and direction (PS-5.1 and PS-5.2), Physical Science students have the foundation necessary to develop an understanding of the concept of acceleration as the rate of change in the velocity of an object, due to either a change in speed or a change in direction.

It is essential for students to understand

- *Constant Velocity or Zero Acceleration*: The first motion diagram shown below is for an object moving at a constant speed toward the right. The motion diagram might represent the changing position of a car moving at constant speed along a straight highway. Each dot indicates the position of the object at a different time. The dots are separated by equal time intervals. Because the object moves at a constant speed, the displacements from one dot to the next are of equal length. The velocity of the object at each position is represented by an arrow. The velocity arrows are of equal length (the velocity is constant).

  The acceleration in the diagram below is **zero** because the velocity does not change.



  Below is a data table which shows an example of what instantaneous velocities might be if measured at equal time intervals for **zero acceleration.** Notice the velocity is the same each time.

Time	Instantaneous velocity
Initial time	15 m/s to the right
After one second	15 m/s to the right
After two seconds	15m/s to the right
After three seconds	15m/s to the right
After four seconds	15m/s to the right

- *Constant Positive Acceleration* (speeding up): This motion diagram represents an object that undergoes constant acceleration toward the right in the same direction as the initial velocity. This occurs when the car speeds up to pass another car. Once again the dots represent, schematically, the position of the object at equal time intervals. Because the object accelerates toward the right, its velocity arrows increase in length toward the right as time passes. The distance between adjacent positions increases as the object moves right because the object moves faster as it travels right.

The acceleration in the diagram below is positive because the object is speeding up.

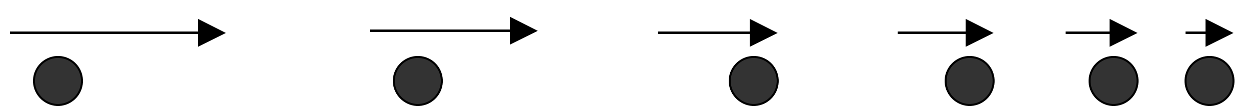
Below is a data table which shows an example of what instantaneous velocities might be if measured at equal time intervals for **positive acceleration.** Notice the velocity is greater each time.

Time	**Instantaneous Velocity**
Initial time	0 m/s to the right
After one second	5 m/s to the right
After two seconds	10 m/s to the right
After three seconds	15 m/s to the right
After four seconds	20 m/s to the right

Teacher note: Sometimes the direction is defined as the positive direction. (Students do not need to know this)

- *Constant Negative Acceleration* (slowing down): This type of motion occurs when a car slows down. The dots represent schematically the position of the object at equal time intervals. Because the acceleration is opposite the motion, the object's velocity arrows decrease by the same amount from one position to the next. Because the object moves slower as it travels, it covers less distance during each consecutive time interval, so the distance between adjacent positions decreases as the object moves right.

The acceleration in the diagram below is negative because the object is slowing down.



Below is a data table which shows an example of what instantaneous velocities might be if measured at equal time intervals for **negative acceleration.** Notice the velocity is smaller each time.

Time	**Instantaneous Velocity**
Initial time	20 m/s to the right
After one second	15 m/s to the right
After two seconds	10 m/s to the right
After three seconds	5 m/s to the right
After four seconds	0 m/s to the right

Teacher note: Sometimes the direction is defined as the positive direction or negative direction. (Students do not need to know this)

- *Acceleration due to a change in direction*:

Time	**Instantaneous Velocity**
Initial time	0 m/s
After one second	5.0 m/s north
After two seconds	5.0 m/s west
After three seconds	5.0 m/s south
After four seconds	5.0 m/s east

  - Students should understand that the velocity of the object above is changing because the direction is changing. The speed of the object remains constant.
    - Because the velocity of the object is changing, it is accelerating;
    - Students need only say that the object <u>is</u> accelerating because the direction (and therefore the velocity) of the object is changing. Students need not consider the rate of acceleration for an object that is changing direction.

It is essential for the students to understand

- That *acceleration* is a measure of the <u>change</u> in velocity (final velocity - initial velocity) per unit of time. When the velocity of an object is changing, it is accelerating.
- That if the object slows down, the change in velocity ($v_f - v_i$) is negative so the acceleration is negative and conversely when the object is speeding up the acceleration is positive.
- That both the change in velocity and the time it takes for that change to occur are important when considering the acceleration of an object.
  - When comparing the acceleration of two objects that have the same change in velocity, the one that undergoes the change in the least amount of time has the greatest acceleration.
  - When comparing the acceleration of two objects that accelerate over the same interval of time, the one that undergoes the greatest change in velocity accelerates the most.
- That acceleration is always measured in velocity (distance/time) units divided by time units. Example: Acceleration is change in velocity divided by time. The unit for velocity is m/s and the unit for time is second so the unit for acceleration is m/s/s or m/s^2. This is derived from velocity (m/s) divided by time (s).
- Students should understand acceleration units conceptually as “change in velocity over time” rather than “distance over time squared”.
  - The most common acceleration units in the metric system are m/s/s or m/s^2.
  - The time units may be different in the velocity part of the equation and denominator such as km/hr per second.
- The velocity of an object can change two ways, so an object can accelerate in two ways:
  - The speed can increase or decrease
  - The direction can change.

It is not essential for students to solve mathematical problems involving acceleration for an object that is changing direction.

Assessment Guidelines:
The objective of this indicator is to *explain* how changes in velocity or time affect the acceleration of an object, therefore, the primary focus of assessment should be to a construct a cause and effect model showing how changes in speed, direction, or time affect the acceleration of an object.

In addition to *explain*, assessments may require that students:

- *Exemplify* how each variable influences the acceleration of an object;
- *Compare* negative and positive acceleration;
- *Summarize* the effect of each variable on the acceleration of an object;
- *Infer* from experimental data the relative acceleration (greater rate of acceleration vs. lesser rate of acceleration) of two objects;
- *Interpret* accelerated motion on a motion diagram;
- *Illustrate* accelerated motion using motion diagrams

Forces and Motion
PS-5 The student will demonstrate an understanding of the nature of forces and motion.

PS-5.4 Use the formula $a = (v_f - v_i)/t$ to determine the acceleration of an object.
Taxonomy Level: 3.2-C Apply Procedural Knowledge

Key Concepts:
Acceleration
Initial velocity
Final velocity
Elapsed time

Previous/Future knowledge: In 8th grade, students analyze the effects of forces (including gravity and friction) on the speed and direction of an object (8-5.3) and predict how varying the amount of force or mass will affect the motion of an object (8-5.4). In Physical Science students are introduced to the concept of acceleration (PS5.3). In Physics students will derive equations to analyze circular motion, trajectory motion, and complex vector problems, all of which begin with a fundamental understanding of the equation introduced here: $a = (v_f - v_i)/t$
The purpose of this indicator is to introduce Physical Science students to the mathematical aspects of acceleration. By calculating, using dimensional analysis in the calculation of acceleration, students will see that the final units for acceleration are m/s/s or m/sec^2.

It is essential for students to
- Interpret a word problem, or laboratory data, involving the motion of an object that is accelerating in one direction and determine the "given" information:
- Differentiate velocity from speed if the direction is given. If velocity is given, students should record the direction.
- Differentiate initial velocity (speed) from final velocity (speed) from the context of the problem.

Teacher note: As this is an introduction to the mathematical application of the concept of acceleration, the units given to students should be consistent. (The units for initial and final velocity should be the same.)

Students need to list the given variables using the correct units:

Variable	Symbol	Examples of units for velocity (or speed)	
Initial velocity (or speed)	v_i = distance/time	5.0 m/s east (5.0 m/s)	5.0 km/h east (5.0 km/h)
Final velocity (or speed)	v_f = distance/time	2.0 m/s east (2.0 m/s)	2.0 km/s east (2.0 m/s)
Elapsed time	t	15 s	15 s

It is essential for students to
- Use the equation $a = (v_f - v_i)/t$ to solve for acceleration only, not for v_f or v_i .
- Substitute the correct values into the equation, including the correct units.
- Mathematically solve the problem, using dimensional analysis to derive the units of the answer. (see dimensional analysis PS-1.5)
- Check to make sure that the units calculated from the dimensional analysis match the appropriate units for the acceleration (distance/time divided by time or distance divided by time-squared).
- Understand that negative acceleration means that velocity is decreasing.

Teacher note: In Physical Science, we will restrict negative acceleration to the case of an object that is slowing down. There are other scenarios that are considered negative acceleration, but they will be addressed in physics.

It is not essential for students to
- Solve problems to convert Standard English units to metric units.
- Solve problems involving scientific notation.
- Solve the equation for initial velocity, final velocity, change in velocity, or elapsed time.

Assessment Guidelines:
The objective of this indicator is to *use* the acceleration formula to determine acceleration of an object, therefore, the primary focus of assessment should be to apply the acceleration formula to a novel word problem or set of experimental data, not just problems that are familiar.

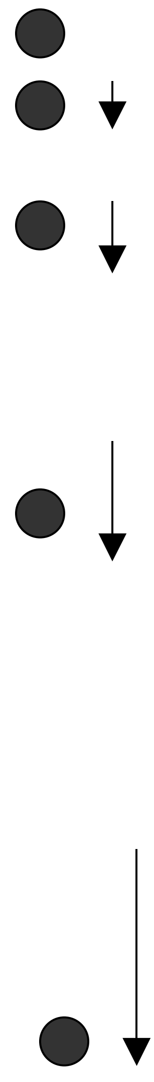
In addition to use, assessments may require that students:
- *Recognize* when the formula should be applied;
- *Identify* the appropriate units for the solution to the problem;
- *Compare data* using the formula.

PS-5.5 Explain how acceleration due to gravity affects the velocity of an object as it falls.
Taxonomy Level: 2.7-B Understand Conceptual Knowledge

Key Concepts:
Acceleration due to gravity: a_g

Previous/Future knowledge: In 8th grade, students were introduced to gravity as a force and the effect that gravitational force has on the speed of objects as they analyzed the effects of gravity and friction on the speed and direction of an object (8-5.3). In Physical Science (PS-5.7) students will address the relationship between force and acceleration in more detail. The major emphasis of this indicator (PS-5.5) is the behavior of objects as they accelerate during free fall, not the reason that they accelerate.

It is essential for students to understand that



- All objects accelerate as they fall because Earth continually exerts a force (gravitational force) on them.

  The diagram depicts the position of an object freefall at regular time intervals. The fact that the distance which the ball travels every interval of time is increasing is a sure sign that the ball is speeding up as it falls downward. If an object travels downward and speeds up, then it accelerates downward.

- When an object is released it accelerates.
- The direction of the gravitational force is always downward.
- The acceleration is in the direction of the force, so the direction of the acceleration is downward as well.
- When an object is dropped from rest, it has an initial velocity of 0.0 m/s.
- The object will accelerate at a constant rate of $9.8 m/s^2$ or m/s/s.
  - This means that the object will speed up at a constant rate of 9.8 m/sec every second it is falling in the absence of air resistance.
- The value, 9.8m/s per s, is called the *acceleration of gravity* and has the symbol a_g.
- Since the object is accelerating because of the gravitational force that is attracting Earth and the object, the velocity of the object continues to increase in speed and continues to fall in a downward direction until it hits the ground.

Students must understand the meaning of the values on the chart in terms changing velocity.

	v_i	v_f
1st s	0.0 m/s	9.8 m/s
2nd s	9.8 m/s	19.6 m/s
3rd s	19.6 m/s	29.4 m/s
4th s	29.4 m/s	39.2 m/s
5th s	39.2 m/s	49.0 m/s

Teacher note: Students may use 10 m/s/s for acceleration due to gravity for ease of calculation. Both 10 or 9.8 may be used on the end-of-course examination.

It is not essential for students to
- Consider the motion of free-falling objects influenced by other forces, such as
  - Air resistance,
  - Exerted forces such as rocket boosters;
- Consider the motion of objects which have been projected upward;
- Consider projectile motion other than straight down;
- Calculate values such as distance fallen, elapsed time, final velocity, or other values.

Assessment Guidelines:
The objective of this indicator is to *explain* how acceleration due to gravity affects the velocity of an object as it falls, therefore, the primary focus of assessment should be to construct a cause and effect model showing how acceleration due to gravity affects the velocity and displacement of an object in freefall.

For general assessment purposes acceleration due to gravity may be given as 10 m/s/s (10 m/s^2).

In addition to *explain*, assessments may require that students:
- *Illustrate* in words, pictures, or diagrams how velocity and displacement change as an object falls;
- *Summarize* how velocity and displacement change as an object falls;
- *Interpret* diagrams of objects in freefall.

PS-5.6 Represent the linear motion of objects on distance-time graphs.
Taxonomy Level: 2.1-B Understand Conceptual Knowledge

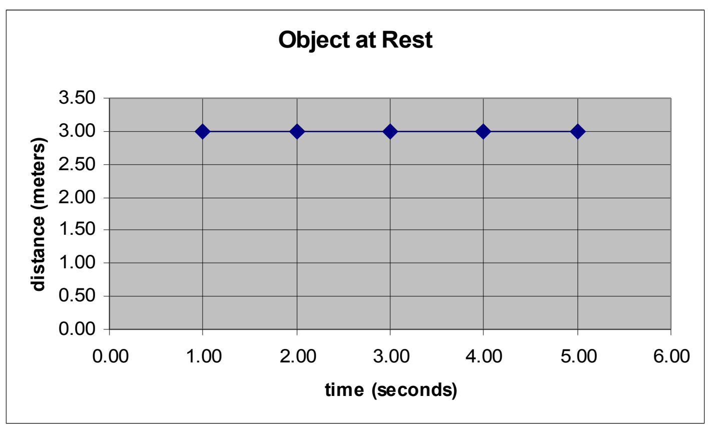
Key Concepts:
Distance/time graphs
Displacement/time graphs
Linear motion
Story graph

Previous/Future knowledge: In 5th grade students, use a graph to illustrate the motion of an object (5-5.5). In 8th grade, students use measurement and time-distance graphs to represent the motion of an object in terms of its position, direction, or speed (8-5.1). In Physical Science, students will again focus only on graphs of distance vs. time, but the focus here will be for students to understand and compare the shape of distance-time graphs for a variety of different types of motion.

It is essential for students to
- Construct distance/time graphs from data showing the distance traveled over time for selected types of motion (rest, constant velocity, acceleration).
- Compare the shape of these three types of graphs and recognize the type of motion from the shape of the graph.
- Discuss in words the significance of the shapes of the graphs in terms of the motion of the objects.

(1) ***An object at rest***
Example:

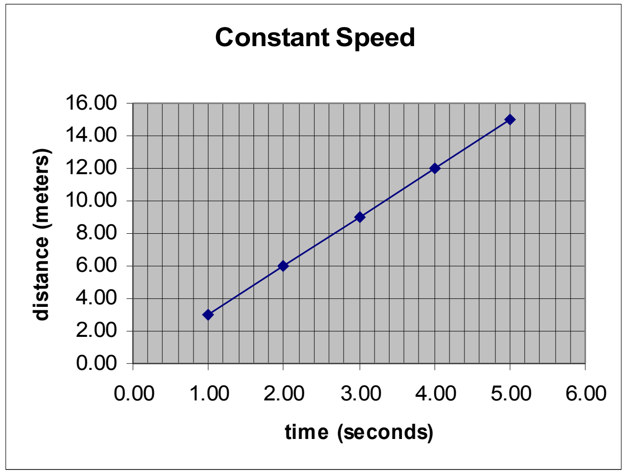
Elapsed Time (s)	Total Distance Traveled (meters)
1.00	3.00
2.00	3.00
3.00	3.00
4.00	3.00
5.00	3.00



The shape of the graph is flat, because between the 1st and 6th second there is no change in distance.

(2) ***An object with constant speed***
Example:

Elapsed Time (s)	Total Distance Traveled (meters)
1.00	3.00
2.00	6.00
3.00	9.00
4.00	12.00
5.00	15.00

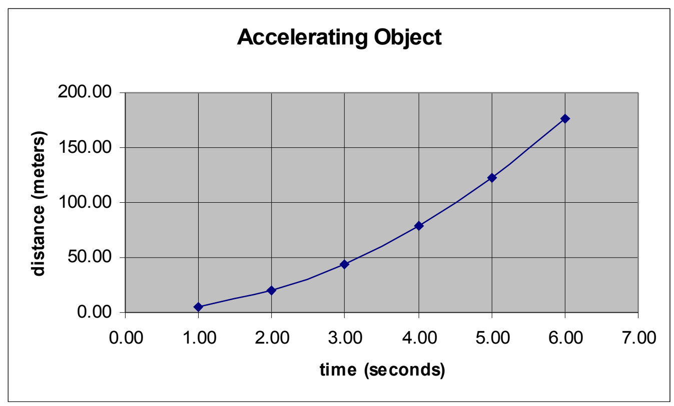


The shape of the graph is a diagonal straight line. The object covers the same amount of distance in each time period. As the time increases, the distance increases at a constant rate.

(3a) ***An accelerating object*** (positive acceleration or speeding up)

Example:

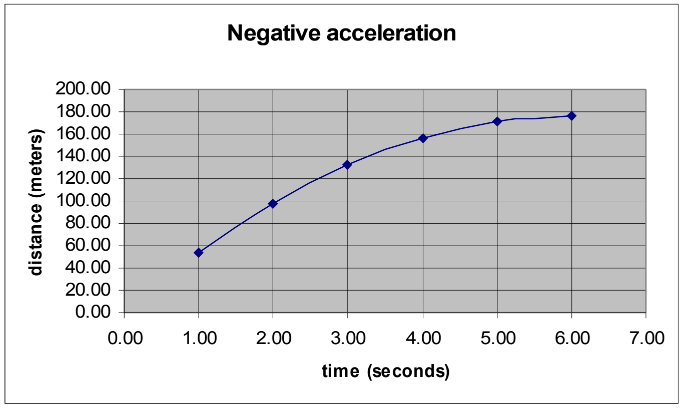
Elapsed Time (s)	Total Distance Traveled (meters)
1.00	4.90
2.00	19.60
3.00	44.10
4.00	78.40
5.00	122.50
6.00	176.40



The shape of the graph is a curve getting steeper because as time goes by, the object covers more distance each second than it did in the previous second so the amount that the graph goes up each second gets more and more.

(3b) ***A negatively accelerating object*** (an object slowing down)
Example:

Elapsed Time (s)	Total Distance Traveled (meters)
1.00	53.90
2.00	98.00
3.00	132.80
4.00	156.80
5.00	171.50
6.00	176.40



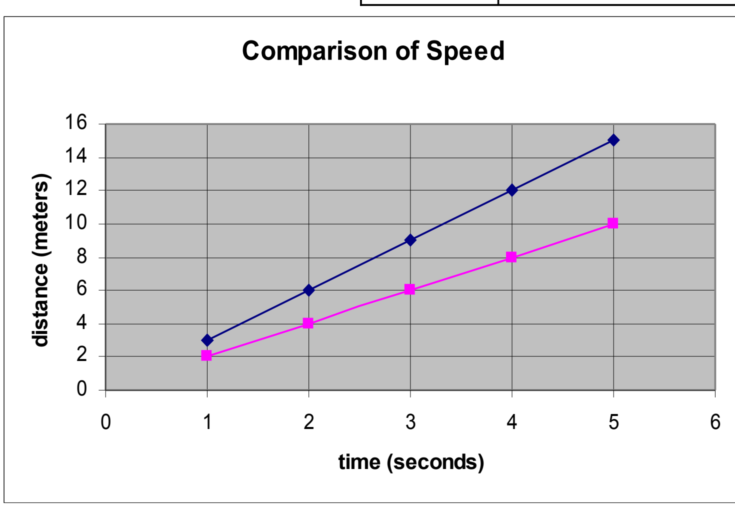
The shape of the graph is a curve getting flatter because as time goes by, the object covers less distance each second than it did in the previous second, so the amount that the graph goes up each second gets less and less.

It is essential for students to

- **C**onstruct distance time graphs from data that <u>compare</u> the motion of objects.
- Discuss the significance of the shapes of the graphs in terms of the relative motion of the objects.

(1) ***A comparison of two objects traveling at different speeds***
Example:

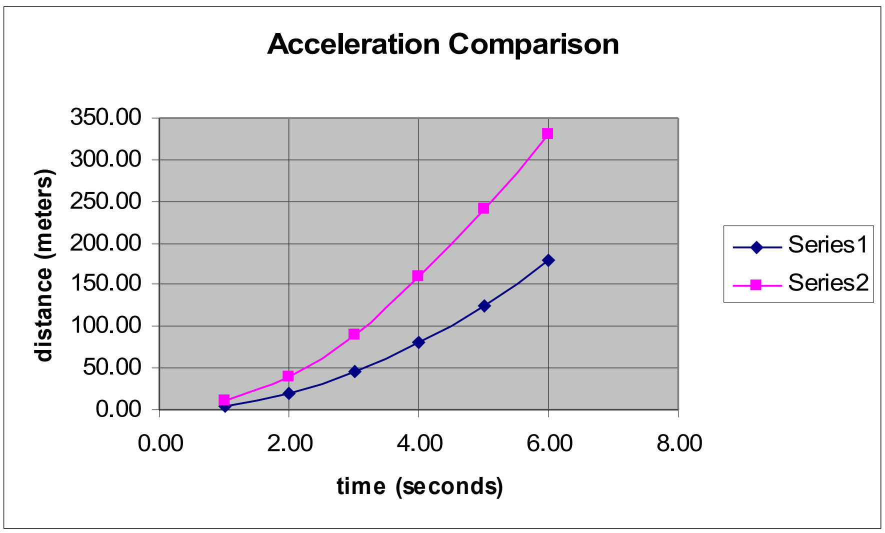
Elapsed Time (s)	Total Distance Traveled (meters) Object 1	Total Distance Traveled (meters) Object 2
1.00	3.00	2.00
2.00	6.00	4.00
3.00	9.00	6.00
4.00	12.00	8.00
5.00	15.00	10.00



Both objects are traveling at a constant speed, but the object represented by the top line is traveling faster than the lower one. You can tell this because the amount that the graph goes up each second (which represents the amount of distance traveled) is more for the top line than for the bottom one. (The top line has a greater slope.)

(2) ***A comparison of two objects accelerating at different rates***
Example:

Total elapsed Time (seconds)	Total distance traveled (meters) Object 1	Total distance traveled (meters) Object 2
1.00 s	5.00 m	10.00 m
2.00 s	20.00 m	40.00 m
3.00 s	45.00 m	90.00 m
4.00 s	80.00 m	160.00 m
5.00 s	125.00 m	240.00 m
6.00 s	180.00 m	330.00 m

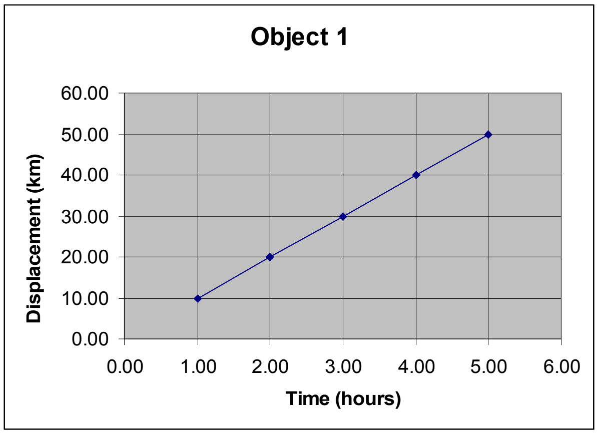


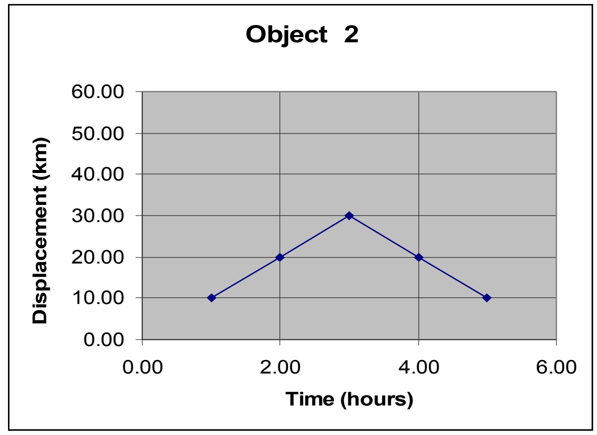
Both of the objects are accelerating, but the Series 2 object (top curve) is accelerating at a greater rate than the Series 1 object (bottom curve). Both objects cover more distance each second than they did during the previous second, but the amount of increase for series 2 is more than the amount of increase for (series 1).

(3) ***A comparison of two objects traveling in different directions at a constant speed***
(to show this, a displacement-time graph is required)
Example:

Elapsed Time (s)	Total Displacement (kilometers) Object 1	Total Displacement (kilometers) Object 2
1.00	10.00 km West	10.00 km West
2.00	20.00 km West	20.00 km West
3.00	30.00 km West	30.00 km West
4.00	40.00 km West	20.00 km West
5.00	50.00 km West	10.00 km West

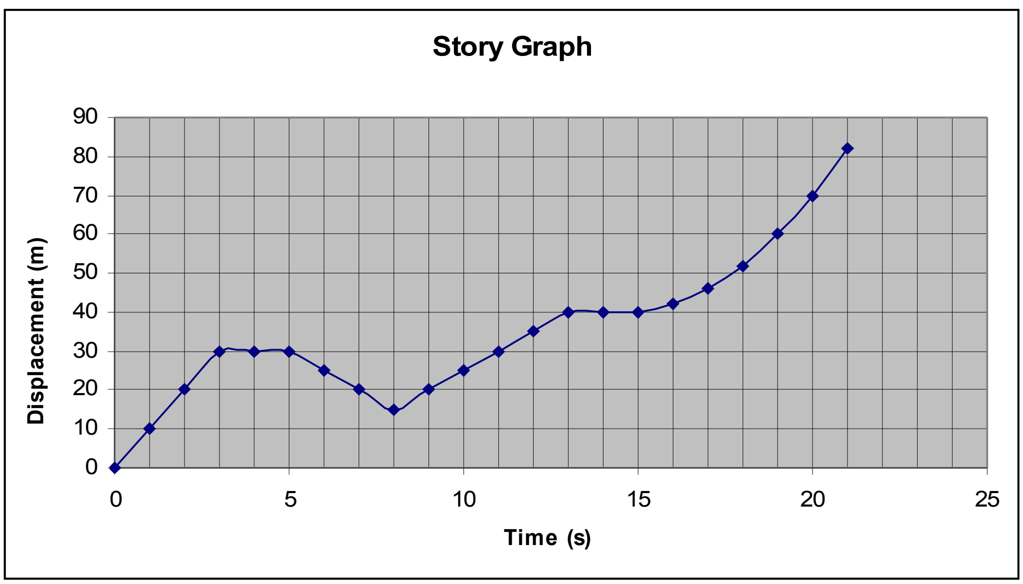
Direction Comparison





These are displacement-time graphs (displacement/location has distance and direction), so it shows how far each object is from the starting point after each hour. **Object 1** gets farther and farther away. At the 3rd hour, **object 2** turns around and comes back toward the start. The speed of each object is the same.

It is essential for a student to infer a possible story given a graph similar to this example.



Possible explanation.

- From 0 to 3 seconds the object is traveling at a **constant velocity away** from the starting point.
- From 3 seconds to 5 seconds the object is **not moving** relative to the starting point.
- From 5 seconds to 8 seconds the object is **moving at a constant velocity toward** the starting point.
- From 8 seconds to 13 seconds the object is moving at a **constant velocity away** from the starting point, at a velocity slower than the motion from 0 to 3 seconds.
- From 13 to 15 seconds the object is **not moving** relative to the starting point.
- From 15 to 21 seconds the object is **accelerating** (speeding up) as it moves **away** from the starting point.

Forces and Motion
PS-5 The student will demonstrate an understanding of the nature of forces and motion.

It is not essential for students to

- Construct or analyze velocity-time or acceleration-time graphs;
- Determine velocity by mathematically calculating the slope of the graphs. Students should be able to interpret the meaning of the "steepness" of a graph;
- Graph any types of velocity graphs other than those which have been addressed such as velocity vs. time graphs.

Assessment Guidelines:
The objective of this indicator is to *represent* linear motion of an object on distance-time graphs, therefore, the primary focus of assessment should be to represent distance/time or displacement/time data in graph form or interpret distance/time or displacement/time graphs. The type of motion is restricted to rest, constant velocity, or constant acceleration. Students should apply their knowledge of graphical analysis of motion to any new set of data, verbal description, or graphical representation.

In addition to *represent*, assessments may require that students:

- *Exemplify* by finding a specific example of a type of graph which is appropriate for a given data set or verbal description of motion;
- *Classify* the type of motion (rest, constant speed, or acceleration) by the shape of a distance time graph;
- *Summarize* the shapes of graphs which represent specific types of motion;
- *Compare* the motion of two objects from graphical representations of their motion;
- *Interpret* distance/time and displacement/time graphs.

Forces and Motion
PS-5 The student will demonstrate an understanding of the nature of forces and motion.

PS-5.7 Explain the motion of objects on the basis of Newton's three laws of motion: inertia; the relationship among force, mass, and acceleration; and action and reaction forces.
Taxonomy Level: 2.7-B Understand Conceptual Knowledge

Key Concepts:
Newton's 1st Law: Law of Inertia, net force, newton (N), inertia, friction
Newton's 2nd Law: applied force
Newton's 3rd Law: Law of Action and Reaction, action force, reaction force

Previous/Future knowledge: In 5th grade students are introduced to net force as they explain how unbalanced forces affect the rate and direction of the motion in object (5-5.3). Also in 5th grade students explain how a change in force or mass affects the motion of an object (5-5.6). In 8th grade, as foundation for Newton's first law, students summarize and illustrate the concept of inertia (8-5.6). Also in 8th grade, as foundation for Newton's second law, students predict how varying the amount of force or mass will affect the motion of an object (8-5.4). In Physical Science, students have an understanding of the difference between constant velocity and accelerated motion. Students can now use Newton's first law of motion to explain how an object's inertia affects its motion in terms of speed and direction. Students can use Newton's second law to explain how applied forces can affect the motion of an object in terms of speed and direction. Newton's third law is an entirely new concept for Physical Science students.

Newton's First Law of Motion
It is essential for students to understand
- That a force is a push or a pull that one object exerts on another object and that in the metric system, force is measured in units called *newtons* (N).
- That a *net force* is an unbalanced force. It is necessary to find the net force when one object has more than one force exerted on it.
- *Newton's First Law* that states that the velocity of an object will remain constant unless a net force acts on it. This law is often called the *Law of Inertia*.
    - If an object is moving, it will continue moving with a constant velocity (in a straight line and with a constant speed) unless a net force acts on it.
    - If an object is at rest, it will stay at rest unless a net force acts on it.
    - *Inertia* is the tendency of the motion of an object to remain constant in terms of both speed and direction.
- That the amount of inertia that an object has is dependent on the object's mass. The more mass an object has the more inertia it has.
- That if an object has a large amount of inertia (due to a large mass):
    - It will be hard to slow it down or speed it up if it is moving.
    - It will be hard to make it start moving if it is at rest.
    - It will be hard to make it change direction.
- That inertia does not depend on gravitational force. Objects would still have inertia even if there were no gravitational force acting on them.
- The behavior of stationary objects in terms of the effect of inertia. Examples might include:
    - A ball which is sitting still will not start moving unless a force acts on it.
    - A ball with a larger mass will be more difficult to move from rest than a smaller one. It is more difficult to roll a bowling ball than a golf ball.

- The behavior of moving objects in terms of the effect of inertia. Examples might include:
  - People involved in a car stopping suddenly:
    - If a net force (braking force) is exerted on the car in a direction opposite to the motion, the car will slow down or stop.
    - If the people in the car are not wearing their set belts, because of their inertia, they keep going forward until something exerts an opposite force on them.
    - The people will continue to move until the windshield (or other object) exerts a force on them.
    - If the people have their seatbelts on when the braking occurs, the seatbelt can exert a force to stop the forward motion of the person.
  - A passenger in a turning car:
    - Consider a person who is a passenger in a car that is moving in a straight path. The passenger in the car is also moving in a straight path.
    - If the car suddenly turns left, the inertia of the passenger causes him to continue to move in the same straight path even though the car under him has turned to the left.
    - The passenger feels as if he has been thrown against the side of the car, but in fact, the car has been pushed against the passenger.
  - If a rowboat and a cruise ship are moving at the same speed, it is more difficult to turn the cruise ship because it has more mass and therefore more inertia.
- The reason that objects often do not keep moving in our everyday experience is because there is often a net force acting on them.
  - Students need to explain how *friction* as a net force slows or stops a variety of everyday objects.
  - If a ball were thrown in distant outer space away from forces, such as friction, it would continue to move at a constant velocity until an outside force acts on it.

Newton's Second Law of Motion

It is essential for students to understand

- *Newton's Second Law* that states, "When a net force acts on an object the object will accelerate in the direction of the net force".
  - The larger the net force, the greater the acceleration. (It is sometimes stated that the acceleration is directly proportional to the net force.)
  - The larger the mass of the object, the smaller the acceleration. (It is sometimes stated that the acceleration is inversely proportional to the mass of the object.)
- In mathematical terms Newton's Second Law states that the net force equals the mass times the resulting acceleration. ($F = ma$)
- Acceleration can mean speeding up, slowing down, or changing direction;
- Friction and air resistance will often be ignored in discussions and problems, but students should be aware of their role in determining the net force.

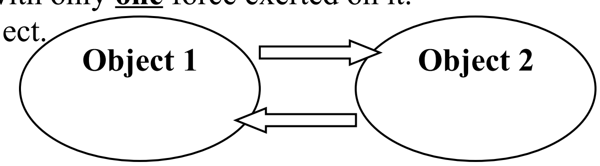
It is essential that students understand

- The motion of objects in terms of force, mass and acceleration.
- *The effects of force***:**
  - *Force magnitude*: If the mass of an object remains constant, the greater the net force the greater the rate of acceleration.

- *Force direction:*
  - If the force is applied to an object at rest, the object will accelerate in the direction of the force.
  - If the force is applied to a moving object in the same direction that the object is moving, the object will accelerate so its speed will increase to a greater speed and continue to travel in the same direction.
  - If the force is applied to a moving object in a direction opposite to the direction that the object is moving, the object will have negative acceleration and slow down from its speed before the force was applied to a slower speed. It will either continue at the slower speed, stop, or begin to move in the opposite direction, depending on the magnitude of the force.
- *The effect of mass:*
  - If the same net force is applied to two different objects, the object with the smaller mass will have a greater acceleration in the direction of the applied force.

It is not essential for students to
- Address forces in directions other than the same or opposite;
- Understand the factors that affect friction;
- Differentiate sliding and rolling friction.

Newton's Third Law of Motion
It is essential for students to understand
- *Newton's Third Law* that states, "When one object exerts a force on a second object, the second one exerts a force on the first that is equal in magnitude and opposite in direction."
  - This law is sometimes called the "*Law of Action and Reaction*".
  - Even though the forces are equal in magnitude and opposite in direction, they do not cancel each other. This law addresses **two** objects, each with only **one** force exerted on it.
    - Each object is exerting one force on the other object.
    - Each object is experiencing only one force.



- Students should describe the motion of familiar objects in terms of action and reaction forces. Examples may include:
  - A swimmer is accelerating forward:
    - The swimmer pushes against the water (action force), the water pushes back on the swimmer (reaction force) and pushes her forward.
  - A ball is thrown against a wall:
    - The ball puts a force on the wall (action force), and the wall puts a force on the ball (reaction force) so the ball bounces off.
  - A person is diving off a raft:
    - The person puts a force on the raft (action force) pushing it, and the raft puts a force on the diver (reaction force) pushing her in the opposite direction.
  - A person pushes against a wall (action force), and the wall exerts an equal and opposite force against the person (reaction force).

It is not essential for students to understand or solve problems involving momentum.

Assessment Guidelines:
The objective of this indicator is to *explain* the motion of objects based on Newton's laws of motion, therefore, the primary focus of assessment should be to construct a cause and effect model that explains the motion of objects in terms of inertia; force, mass, and acceleration; and action and reaction forces.

In addition to *explain*, assessments may require that students:
- *Exemplify* Newton's Laws of Motion;
- *Compare* the inertia of different objects of different mass;
- *Compare* the rate of acceleration of objects with different masses or the rate of acceleration of an object when subjected to different forces (in terms of magnitude and direction);
- *Compare* action and reaction forces in terms of magnitude, direction, source of force (which object) and recipient of the force (which object);
- *Summarize* the principles of Newton's Laws of Motion;
- *Illustrate* Newton's Laws of Motion with pictures, words, or diagrams.

Forces and Motion
PS-5 The student will demonstrate an understanding of the nature of forces and motion.

PS-5.8 Use the formula F = ma to solve problems related to force.
Taxonomy Level: 3.2-C Apply Procedural Knowledge

Key Concepts:
Applied force
Frictional force
Net force

Previous/Future knowledge: 8th grade students analyzed the effects of forces (including gravity and friction) on the speed and direction of an object (8-5.3). They also predicted how varying the force or mass will affect the motion of an object. (8-5.4) This indicator for Physical Science addresses the mathematical dimension of force by solving problems related to force, mass, and acceleration.

It is essential for students to
- Understand the correct context for the variables in a word problem.
- Understand that a *newton* is defined as the amount of force necessary to accelerate a 1.0 kg object at a rate of 1 meter/second/second. force = (mass)(acceleration)
    - The newton is a *derived* unit, so when you multiply mass times acceleration, if mass is in kilograms and acceleration is in m/s/s, you have the proper units for newtons (kg·m/s/s or kg· m/s^2).
- Mathematically solve problems for force, mass, or acceleration, using dimensional analysis to identify the units of the answer. (See dimensional analysis PS-1.5)
- Determine the "given" information using the correct units,
    - Mass should be given in kilograms (kg),
    - Acceleration in (m/s/s, or m/s^2), and
    - Force in newtons. (N)
- Solve problems for any of the variable in the formula, F = ma. For example, the problem may give net force and mass and the student must find the acceleration (a = F/m).

It is not essential for students to
- Solve problems in Standard English units or convert Standard English units to metric units.
- Solve problems involving scientific notation.
- Solve two-step problems that require first finding acceleration from initial velocity, final velocity and time.
- Solve problems involving friction.

Assessment Guidelines:
The objective of this indicator is to *use* the formula, F=ma, to solve problems related to force, therefore, the primary focus of assessment should be to apply the mathematical formula, F = ma to novel word problems or new sets of data, not just problems that are familiar.

In addition to *use*, assessment may require that students:
- *Apply* procedures for manipulating the formula for Newton's Second Law to solve for any of the variables when given the other two;
- *Recognize* each of the variables;
- *Summarize* the interrelationships among the variables.

Forces and Motion
PS-5 The student will demonstrate an understanding of the nature of forces and motion.

PS-5.9 Explain the relationship between mass and weight by using the formula $F_W = ma_g$.
Taxonomy Level: 2.7-B Understand Conceptual Knowledge

Key Concepts:
Force-weight (F_w)

Previous/Future knowledge: In the sixth grade students used a spring scale to measure forces including weight (6-1.1). In the 8th grade students analyzed the effects of forces (including gravity and friction) on the speed and direction of an object (8-5.3). In the 8th grade students explained the difference between mass and weight by using the concept of gravitational force (8-4.8).
In Physical Science students will explain the mathematical relationships among weight, mass, and acceleration due to gravity.

It is essential for students to understand
- The weight of an object is the force that gravity exerts on that object.
  - The weight of an object depends on its mass.
  - Given the mass of an object, its weight can be calculated using Newton's Second Law.
  - When an object is dropped, it accelerates at $9.8m/s^2$. Because there is acceleration, there must be a force.
  - The force is equal to the mass times the acceleration. ($F_w = ma_g$)
  - The force called weight is equal to an object's mass times the acceleration due to gravity. ($9.8m/s^2$)

It is essential for students to
- Solve problems involving the relationship among the weight and mass of objects and the acceleration of gravity using the formula $F_w = ma_g$. (This formula is sometimes written, $w = mg$.)

It is not essential for students to
- Solve problems in Standard English units or convert Standard English units to metric units.
- Solve problems involving scientific notation.
- Solve multi-step problems for this indicator that involve:
  - Determining the acceleration of an object from the initial velocity, final velocity and the time;
  - Determining the mass of an object from its weight in order to use the mass in another context.
- Solve problems that require considering opposing forces, such as wind resistance, or considering the forces on objects moving upward.

Assessment Guidelines:
The objective of this indicator is to *explain* the relationship between mass and weight, therefore, the primary focus of assessment should be to construct a cause and effect model of the relationship between mass and weight, using the formula ($F_w = ma_g$) as a basis for that relationship.
A second focus of assessment should be to apply the formula $F_w = ma_g$ to novel word problems or a new set of data, not just problems that are familiar.

In addition to *explain*, assessments may require that students:
- *Apply* procedures for manipulating the formula $F_w = ma_g$
- *Summarize* the relationship between the mass and the weight of an object;
- *Compare* the quantities of mass and weight in terms of the value each is measuring, the units for each, and the relationship between the two.

Forces and Motion
PS-5 The student will demonstrate an understanding of the nature of forces and motion.

PS-5.10 Explain how the gravitational force between two objects is affected by the mass of each object and the distance between them.
Taxonomy Level: 2.7-B Understand Conceptual Knowledge

Key Concepts:
Newton's Law of Universal Gravitation

Previous/Future knowledge: In the 8th grade students explained how gravitational forces are influenced by mass and distance (8-4.6). In Physical Science students will understand the new concept that all objects exert forces on all other objects.

It is essential for students to understand
- *Newton's Law of Universal Gravitation* states that there is a force of attraction between all objects in the universe.
- The Law of Universal Gravitation applies to <u>all</u> objects.
- The size of the gravitational force of attraction between two objects depends on the **<u>mass of both objects</u>** and the **<u>distance</u>** between objects.
  - The force is greater when the mass of either of the two objects is greater.
    - Earth, with its huge mass, has a relatively large attractive force with all of the objects near its surface.
    - The moon has less mass than Earth, so the moon has less attraction for objects on its surface than Earth does. (Objects on the surface of the moon weigh less than on Earth because the gravitational force between the object and the moon is less than the gravitational force between the object and the Earth.)
    - The reason the attraction is not noticed between ordinary sized objects that are on earth is that the force that Earth exerts on objects is so great relative to the force of attraction between other objects. (negligible relative to the attraction of the object to Earth).
  - The closer the two objects are, the greater the force
    - When an object, such as a space vehicle, moves away from Earth, the gravitational attraction between Earth and the vehicle becomes less and less.
- That if the force acting on a falling object is the same as the force acting on Earth, the object accelerates toward Earth while Earth doesn't seem to accelerate at all. This is because the mass of Earth is so huge, the force causes only a very tiny acceleration, one that is undetectable by humans.

It is not essential for students to
- Understand the equation that represents Newton's Law of Universal Gravitation.
- Use Newton's Law of Universal Gravitation to solve any problems quantitatively.
- Understand the "inverse square" relationship of force and distance.
- Understand the significance of the Gravitation constant.

Forces and Motion
PS-5 The student will demonstrate an understanding of the nature of forces and motion.

Assessment Guidelines:
The objective of this indicator is to *explain* how gravitational force is affected by mass and distance, therefore, the primary focus of assessment should be to construct a cause and effect model showing the effect of the mass of any two objects and the distance between the objects has on gravitational force between the objects. Students should construct cause and effect models that explain the behavior of familiar objects (falling objects, weight on the moon) in terms of the gravitational model.

In addition to *explain*, assessments may require that students

- *Exemplify* how mass and distance influence the magnitude of gravitational force;
- *Compare* the relative gravitational force of two sets of objects with different masses or the relative gravitational force of sets of objects with different distances between them;
- *Identify* which object would exert the greatest force depending on its mass or proximity to other objects;
- *Summarize* the factors that affect gravitational force;
- *Illustrate* with words, pictures, or diagrams the Law of Universal Gravitation.